INTRODUCTION

The 30 cubic engine, which we acquired, was of vertical crankshaft design for use with a lower unit of an outboard motor. This engine weighed in at 65 lbs. with the modified Bendix magneto system attached. Overall dimensions can be obtained by studying the enclosed blueprints.

This engine represents a basic prime mover and is the ultimate in simplicity. Even with its apparent simplicity, there are certain conditions which must be met or this engine will not function properly. It is the purpose of this blueprint and information package to present the conditions necessary to build a successfully operating engine.

Another purpose of this blueprint and information package is to encourage participation in our engine building project as described in our first letter. By better understanding why this engine operates as it does, you will be better prepared to decide if you would like to be the proud owner of a four cylinder, 60 cubic inch, horizontal crankshaft, 230 H.P. engine. This engine building project will be a non-profit venture for the sole purpose of reducing the cost per engine so that truly interested individuals can obtain an engine at a reasonable price. A supplementary information package will be compiled in the near future for those individuals who can definately say, "Yes, I want to own one of these engines."

This engine has been called a "mono-cycle" engine because each piston functions like the piston in a two stroke engine. However, this engine functions only in multiples of two and therefore, comes the term "mono-cycle." This engine can also be classified as a "free piston engine" as the crankshaft serves only to transmit the reciprocating motion and energy of the piston rod assembly into rotary motion and energy at the drive point. The piston rod assembly can actually function without the crankshaft. However, without the crankshaft there is no way of utilizing the power created by this assembly. This engine utilizes to the fullest advantage all of the conditions as set forth by Beau De Rouche (see articles included, plus tapes with Russ). After carefully studying and verifying the material contained in this package and the mechanical and chemical data given in the "Bourke Engine Documentary," it should become clear why this engine performs as it does.

The engine, from which the enclosed blueprints were made, used ball bearings in the end plates. As per the discussions on the tapes, the use of ball or roller bearings should be avoided and slipper bearings should be used throughout the engine. All tolerances for sliding fits, running fits, etc. can be obtained from an Engineering Handbook. All parts should be accurately machined as described in the "Castings and Machining" section of this package.

All of the different sections of this package are designed to be as self-explanitory as possible. However, if after digesting all of this material and all the technical information contained in the "Bourke Engine Documentary" you still have some questions, please feel free to contact me.

DESIGN CHANGES

This section is devoted to many of the improvements Mr. Bourke made in his 400 cubic inch engine and improvements which are the result of recent technology. All of these changes will be made in the proposed engine.

1. PRE-LOADING OF PISTONS - On the 400 cubic inch design Russ pre-loaded his pistons in a more precise and efficient way. Instead of splitting the skirt and pre-loading, Russ added another ring groove at the bottom of the piston skirt and used "Marcel" and a double ringing system in this ring groove and the second ring groove down from the head of the piston. The double ringing system was accomplished by surface grinding two rings to ½ of their original thickness (or to the required thickness to accommodate the "Marcel") and securing this double ring with two brass pins at 180° apart. Before installing the double ring, a piece of "Marcel" is cut to length so that when fully depressed it will just fit in the bottom 180° of the ring groove between the two brass pins. The two rings are then installed and the "marcel" "pushes" the cam ground piston upward to seal the intake ports, exhaust ports, and oil hole. This system insures proper pre-loading of the piston in the simplest manner possible. Should the "Marcel" become fatigued after many years of operation, it is a simple procedure to pull the cylinder, pull off the rings, and replace the "marcel".

2. OIL COOLING - The use of oil cooling was highly recommended by Russ because this will make the engine completely self-contained. The use of water cooling would require a separate pump and air cooling should be avoided because of hot spots and resultant warpage. To convert the engine to oil cooling, one simply needs to drill the present water cooling holes into the crankcase area and seal off or eliminate the present water passages. The oil slung from the rapidly turning crankshaft is forced through the cooling holes into the cylinder cooling jacket. This oil is then forced out the top outlet of the cylinder cooling jacket to an oil cooler or copper tubing attached to an aluminum-skinned aircraft. This cooled oil is then fed back into the crankcase for re-cycling.

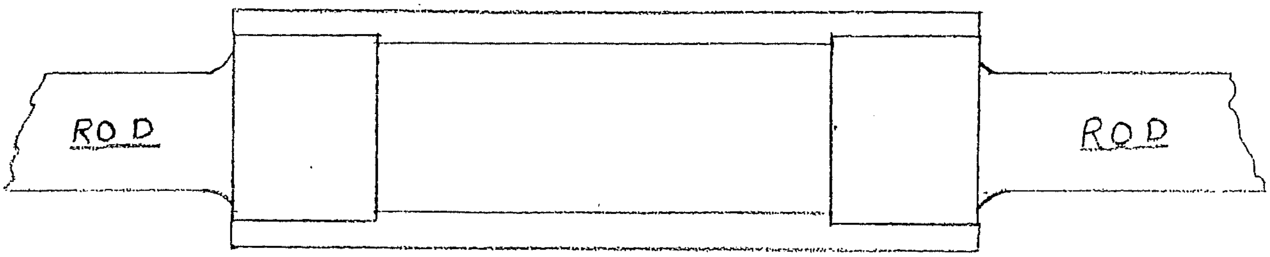
3. OILING SYSTEM - The oiling system on the "400" was also slightly modified to accommodate the use of slipper bearings throughout. The oiling system is completely self-contained and works as follows: The crankshaft has rifle drilled holes from journal bearings (slipper bearings) to the slipper bearings on the throw (all diagrams on "400" in Bourke Engine Documentary). The rapidly turning crankshaft causes the oil to be forced out through the throw slipper bearing via centrifugal force. This in turn draws more oil in through the main journal slipper bearings which are fed via the pressure relief bypass designed into each cylinder. This pressure relief bypass prevents oil from being forced past the piston and thus insures that the delicate fuel to air ratio of this engine is not upset. The oil is forced into the rifle drilled oiling holes on each cylinder by the oil that is thrown from the rapidly turning crankshaft. Thus, one can see from the above that the oiling system is completely automatic and self-contained and does not require the use of an oil pump as in a conventional engine.

4. SLIPPER BEARINGS - as indicated throughout this presentation, the use of ball or roller bearings should be avoided. All of the slipper bearings used throughout the "400" engine were of the same design to facilitate standardization of parts.

5. BREAKERLESS ELECTRONIC IGNITION SYSTEM - The breakerless electronic ignition system is a result of technological advances. Russ utilized a modified Bendix magneto system on the 30 cubic inch design. This magneto system had mechanical breakers and its limiting speed was around 15,000 R. P. M.. Russ indicated that the only two limiting factors on the speed of this engine was the ability of the ignition system to produce a spark fast enough and critical piston speed. With the electronic ignition system, there are no mechanical breakers and therefore this type of system can produce a spark which well exceeds the other limiting factor of critical piston speed. The critical piston speed of any engine is expressed in feet of travel per minute and can be found in an Engineering Handbook. Russ indicated that a safe operating speed for his 30 cubic inch would be around 15,000 R.P.M. (2 3/4 inch bore, 2½ inch stroke).

6. CRANKSHAFT - The crankshaft on the "400" is rifle drilled to accommodate the self-contained oiling system as described in #3 of this section. The crankshaft on the proposed engine will be similar in design to the one used on the "400."

7. YOKE PLATES - The yoke plates on the 30 cubic engine were perfectly flat and Russ depended on the three "Hollow Krome" bolts to absorb the shearing forces created at this point in the engine (explained in tapes). Russ recommended machining a ridge on the yoke plate so the edge of the rod could rest against this ridge (see diagram below). With this ridge incorporated into the yoke plate, the entire face of the plate would have to be sheared off to cause a failure. The rod width in this type of setup would have to be increased slightly to accommodate the ridge thickness and maintain the same tolerances which existed in this original engine.

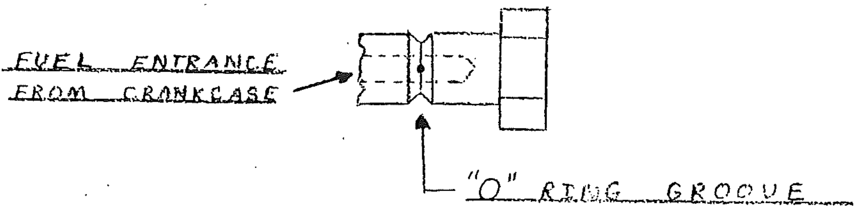


FUEL SYSTEMS

Providing the proper fuel-to-air ratio for this engine represents the most difficult obsticle to overcome. All carburetors which are manufactured for conventional engines are designed to provide the desired fuel-to-air ratio for that engine. This engine requires a constant fuel-to-air ratio of 40 to 1 throughout the entire speed range. A conventional carburetor operates between 12 to 1 and 15 to 1 at normal operating speeds. This mixture is normally richer at idle and richer when the engine is running at maximum recommended speed. Conventional carburetors also have accelerator wells, etc., which can not be used with this engine. Several attempts to run our engine with modified conventional carburetors have convinced us that a mechanical carburetor can not give us the desired fuel-to-air ratio on a consistant basis throughout the entire speed range. After careful study, we feel that there is now available a complete fuel system which can meet the needed requirements of this engine - electronic fuel injection.

The "brain" of the electronic fuel injection system is programmed to give the desired fuel-to-air mixture for a conventional engine. This "brain" then activates a fuel injector to provide the precise amount of fuel needed to meet that operating condition. To adapt the electronic fuel injection system to this engine would require re-programming the "brain" to provide the consistant 40 to 1 fuel-air mixture needed. Two electronic engineers questioned have indicated that re-programming the "brain" would be a rather simple matter, because this would provide a consistant fuel-to-air ratio instead of the variable which is now provided in the conventional engine. They have also indicated that precise adjustment of the fuel-to-air ratio is possible through electronic controls. We intend to pursue the development of this type of fuel system for the proposed engine building project.

Another type of fuel system which would be quite compatible to a constant duty use would be the use of simple fuel injectors (see picture). This fuel injector is nothing more than a machined piece of brass with an "O" ring groove and "O" ring. This fuel injector is inserted in the bypass cavity on the 30 cubic engine. As the piston starts to travel towards TDC there is a partial vacuum formed. The fuel in this injector and connecting passages is at atmospheric pressure and thus forces its way past the "O" ring into the bypass cavity. When the piston skirt uncovers the intake ports, the pressure equilizes and the "O" ring snaps shut. Russ recommended starting out with a #60 drill to drill the six small holes under the "O" ring. He indicated experimentation with different sizes of holes would be necessary to reach the desired mixture and speed for the intended application. The disadvantage of this fuel injector is that the engine speed is not variable as with the electronic fuel injection system.



CASTINGS AND MACHINING

CASTINGS

All castings are to meet the highest quality standards. It is very important that good pattern making and casting procedures be used to insure quality parts. Consistant wall thickness is necessary on the cylinder to prevent warpage of the cylinder during engine operations. Warpage could result in disasterous engine failure. Consistant wall thicknesses are also important on the piston and crankcase.

In small quantities, castings may be more economically made by investment casting process instead of sand castings. Investment casting should also be considered for crankshaft, rods, counterweights, and saddle. If you are not familiar with the investment casting process, consult your local library.

It is beyond the scope of this text to present the details involved in the pattern making and casting processes involved in making this engine. Several books on pattern making and castings procedures are available for study from your local library. Valuable assistance can also be obtained from local pattern making shops and foundrys.

MACHINING

It is beyond the scope of this text to provide the speeds, feeds, machining operations involved, surface finishes involved, tolerances, etc. on this engine. All of the above can be obtained from an Engineering Handbook and/or consultation with an experienced machinest and mechanical engineer. This section will describe what conditions are necessary to build a successful engine.

The crankcase is precision machined in both the horizontal and vertical planes. On this engine the horizontal plane (centerline of piston rod assembly) and the vertical plane (centerline of the crankshaft) meet at an invisible center. All machining operations are to be done using this invisible center as a referance point and tolerances must be held to zero on all machining done within these two planes. Zero tolerances are a must because the slightest out of tolerance condition will magnify itself thousands of times while the engine is running at high speeds and this can result in engine failure (very disasterous at 15,000 R.P.M.). Long holes are rifle drilled and all other tolerances are as specified on the prints.

The assembled yoke plate - rod assembly must be ground to proper tolerances with zero runout. Again zero runout is necessary to prevent destructive forces from building up in this engine at high speeds.

The piston is cam ground to provide a good seal to the intake ports, exhaust ports, and oiling hole. Failure to cam grind the piston would result in oil being forced around the piston skirt which would then upset the delicate fuel-to-air ratio needed. The intake and exhaust ports would also not seal properly and poor performance would result.

Standard machining procedures are used on the cylinders, however, one must insure the horizontal plane (centerline or cylinder bore) and the vertical plane (flange at base of cylinder for mounting to crankcase) are at a 90^{o} angle to each other with zero tolerances.

End plates must be machined to hold the crankshaft in the correct vertical plane in relation to the horizontal plane of the piston rod assembly (see machinging of crankcase). Russ recommended using dowel pins to correctly position the end plates to the crankcase.

Other items which are noteworthy are:

a. There are no gaskets used in this engine. All sealing surfaces are metal to metal, except for cooling holes, and oiling holes which have an "O" ring seal.

b. All parts should be rough machined and then normalized before finish machining. Rough machining causes stress in the metal which, if not normalized, can cause warpage of precision machined parts.

ASSEMBLY INSTRUCTIONS

The engine is assembled in the following manner:

1. Install "O" rings on rod bushings.
2. Insert rod bushings into crankcase.
3. Insert both rods through the rod bushing via the crankcase.
4. Install one yoke plate with hollow "Krome" screws. This connects the two rods together.
5. Assemble the slipper bearing onto the throw of the crankshaft.
6. Install the crankshaft through the slot in the yoke plate which has been installed in step #3.
7. Install second yoke plate and secure with plastic lock nuts.
8. Install crankshaft throws and secure with bolt, castle nut, and cotter pin (see prints).
9. Install seals and bearings in end plate.
10. Install end plates onto crankcase and secure with nuts and flat washers.
11. Install seal into bushing retainer.
12. Install "O" ring over rod which fits into rod bushing and acts as a back up ring for the seal.
13. Install bushing retainer and secure with four cap screws. Safety wire these cap screws.
14. Install saddle and saddle pin onto the rod.
15. Install piston (with rings installed) over saddle and secure with piston pin (be sure cam ground side is up - sealing exhaust and intake ports plus oiling holes).
16. Install cylinder and secure with four nuts and flat washers.

As one can see from the above, this engine is easily assembled. If the engine needs to be rebuilt (after several thousand hours of use) it can be completely dis-assembled and re-assembled in about one hour. The only parts which <u>might</u> need replacing for complete rebuilding are:

1. Rod bushings (will probably be O.K.)
2. All "O" rings and seals
3. Rings
4. Slipper bearings

This rebuilding process would probably cost around $30 to $40 and would prepare the engine for several thousand more hours of use.

The assembly instructions given are for a two cylinder engine and would change slightly for a four cylinder model.

DETAILS ON THE ENCLOSED PRINTS

1. Carburetor Mounting Plate: This part may be eliminated depending on the type of fuel system used (see section on fuel systems).

2. Piston and Related Cut-away Views: Piston design on this engine is extremely important. Turbulating fins are designed to transfer the incoming charge to the top of the cylinder in a cyclonic or whirlpool motion. This is necessary to prevent any of the incoming charge from being lost through the exhaust ports until the rings can seal these ports off. The pistons are cam ground (see section on castings and machining) and pre-loaded to insure proper sealing of the intake ports, exhaust ports, and oiling hole. On this engine the pre-loading was accomplished by splitting the piston skirt and then peening (either electronically or mechanically) these skirts to give the necessary "push" to seal the above mentioned ports and oil hole. A different method of pre-loading was used on later design engines (see section on design changes). Piston pre-loading is also necessary, because of heat transfer, as this allows the piston to start transferring heat immediatley to the cylinder wall. If the piston was not pre-loaded, by the time the piston became hot enough to expand and start to transfer heat to the cylinder walls, it would sieze. Brass pins are necessary to keep the rings from rotating. If the rings were allowed to rotate, ~~it~~ they would break when the joint passed over a port. All oil grooves are clearly marked. This piston was made from Alcoa 365 heat treated aluminum alloy. All internal ribs, etc. are necessary for strength and heat transfer to incoming charge. Do Not use chrome or chrome plated piston rings with this engine. Chrome plating may chip off and cause continuous overheating in all future operations. Butt cut piston rings of low tensile strength are preferred as the rings only act as a seal and are not responsible for centering the piston in the bore until the piston warms up, as in a conventional engine. Piston rings of low tensile strength also cause less wear on the cylinder walls.

3. Cylinder, Sleeve, and Related Cut-away Views: The cylinders are cast from Alcoa 365 heat treated aluminum. This cylinder was water cooled. However, oil cooling is recommended as the system can then be made fully automatic and self-contained (see design changes). The cooling jackets as shown are approximate because of the impossibility of accurately measuring the internal dimensions from the cylinder. The important aspect on cylinder design is to maintain a consistant wall thickness (see Castings and Machining) to prevent warpage. There is no cooling jacket around the head of the cylinder, as a hot head helps to promote the hydrogen cylce. Air cooling of anything except the head should be avoided as there are always hot spots on air cooled engines. Hot spots in this engine would result in warpage of precision machined and aligned components and could result in disasterous engine failure. The two .1495 inch diameter holes located above the exhaust ports serve as compression relief during starting and slower speeds. These holes are tapped so that they can be plugged if desired.

4. Rod Bushing and Bushing Retainer: The rod bushing can be made from a standard bronze bushing machined to meet the needed requirements. The "O" rings are designed to seal the bushing to the case and the smaller "O" ring acts as a back up ring on the seal to keep the oil in the crankcase,

and the pressure under the piston from entering the crankcase. The rod diameter and the piston pin diameter are the same, thus requiring only one reamer for the rod bushing, saddle, and piston. The bushing retainer is designed to hold the indicated seal and, when in position, holds the rod bushing. The bushing retainer is in turn held in place by four cap screws, which are safety wired in place.

5. Saddle and Saddle Pin: The saddle and saddle pin are made from 1030 steel. Note the internal groove in the saddle to allow the hollow rod to "breathe" in and out with each stroke. The saddle pin is only designed to hold the saddle to the rod, as there is no pressure on this pin, because the piston is always under a positive load and is "pushing" on the rod.

6. Intake Cover Plate, Counterweight Holding Bolt, and Piston Pin: The intake cover plate is made of aluminum, and is necessary to cover the intake ports which are drilled into the cylinder wall from the intake-exhaust side of the cylinder. The counterweight holding bolt is a standard bolt which holds the counterweights to the crankshaft. The castle nut is installed and held in place by a cotter pin. The crankshaft, with counterweights and slipper bearing installed, is then statically and dynamically balanced. The piston pin is a standard "off the shelf" item which has aluminum caps installed on the ends to prevent scouring of the cylinder walls.

7. Counterweights: The counterweights are made of 1030 steel. They are designed to rotate in the same diameter as the outside of the slipper bearing. This allows complete dynamic balancing of the crankshaft assembly throughout the entire speed range. Note the slot which intersects the hole drilled for the counterweight holding bolt. This slot allows oil to enter the throw section of the crankshaft for oiling of the slipper bearing. The oiling system was changed on his 400 and represents a better overall system (see design changes).

8. Rod: The rod is made of 1030 steel. Note the rod is hollow to add rigidity and to allow cooling by the incoming charge on each stroke. All wearing surfaces are case hardened and ground.

9. Yoke Plates: The yoke plates are nothing more than two pieces of flat 1030 steel plate which serves to connect the rods. On this engine the bolts absorbed all of the shearing forces. On his 400, Russ machined a ridge for the rod edges to rest against (explained in tapes - see design changes).

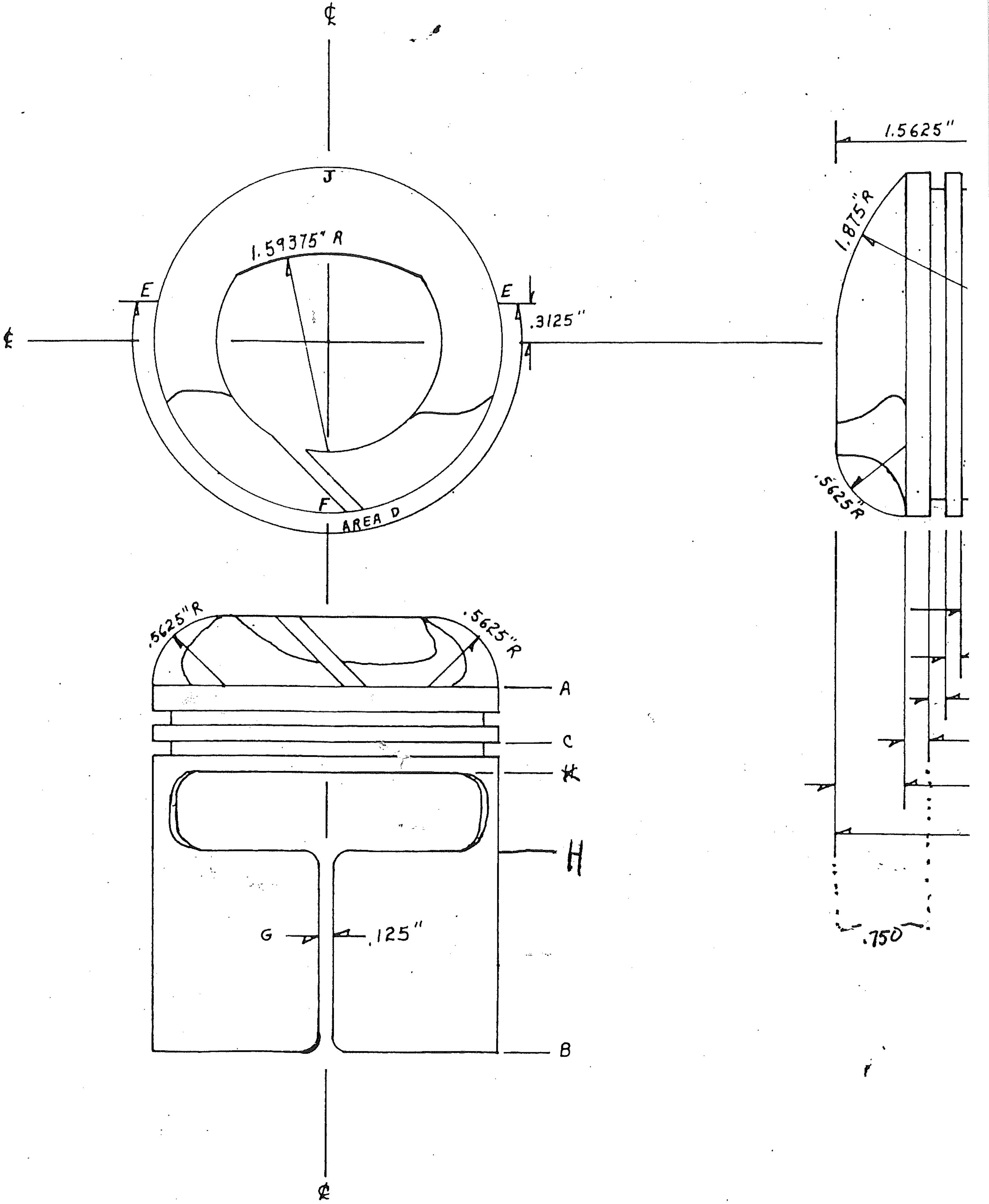
10. Slipper Bearing: The slipper bearing allows the engine to safely run at the speeds it does. Because of its design, this bearing can safely run at speeds just a little under three times the critical speed of a single journal bearing. Because of its simplicity of design, operation, and safety, Russ recommended using it throughout the engine. Outer race is Ampco 18-22, middle race is steel, hardened and ground to the required dimensions, and the inner race is Ampco 18-22. The inner race is split for assembly purposes and has the indicated oil grooves.

11. Crankshaft: The crankshaft on this engine is made from 1030 steel also. The left end of the crankshaft is the drive end. The right end

of the crankshaft was made to adapt to a modified Bendix magneto. Breakerless electronic ignition would be an excellent ignition system for this engine as it has the capacity to keep up with this engine at the higher speeds. The crankshaft was machined from solid plate stock. On the proposed four cylinder, 60 cubic inch engine, the crankshaft would be a solid assembly with throws 180° apart, and with the improved oiling system (see design changes).

12. End Plate: The end plate is made of aluminum and has roller bearings. Russ did not recommend roller bearings and advised the use of the slipper bearing (see design changes). The oiling system for the roller bearing is easily seen but would change slightly with the use of slipper bearings (see design changes). The top plate on this engine was slightly different because this engine was of vertical crankshaft design (different oiling procedure for top bearing versus bottom bearing) and the top base plate was designed to adapt to the modified Bendix magneto system. The groove running the full circumference of the bottom plate is for distribution of fuel to the fuel injectors via the crankcase, if injectors were to be used. Oil exposed surfaces are epoxy-vacuum treated to prevent oil seepage through the pores in the aluminum.

13. Crankcase: The crankcase is made from Alcoa 365 heat treated aluminum. All oil exposed surfaces are epoxy-vacuum treated to prevent oil seepage through the pores in the aluminum.. The crankcase is the most difficult part to make as it has to be precision machined to exacting tolerances. Because of the complexity of the crankcase, a casting drawing and a machining drawing has been included. This crankcase is for a vertical crankshaft engine. However, to change to a horizontal crankshaft engine would only require rotating the intake passages, cylinder oiling hole, oil (or water) cooling holes, and the fuel injection hole 90°. A horizontal crankshaft setup can be studied by analyzing the drawings of the Bourke 400 in the "Bourke Engine Documentary." All passages are marked for reference to matching parts of the engine. The crankcase for the proposed 4 cylinder, 60 cubic inch engine would be similar in design to the Bourke 400 crankcase but, on a smaller scale.


℄
J
1.59375" R
E
E
.3125"
℄
F
AREA D
.5625"R
.5625"R
A
C
~~K~~
H
G
.125"
B
℄
1.5625"
1.875"R
.5625"R
.750